Heavy Quark Production and Modification in d+Au Collision in PHENIX

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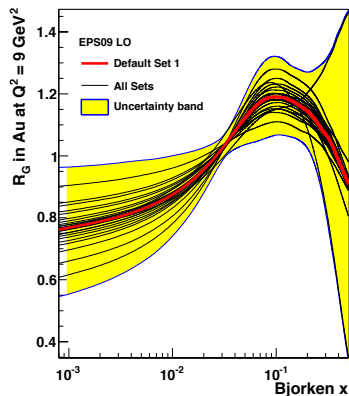
Augustana College
For the PHENIX Collaboration

April 8, 2014

Outline

- ▶ Accessible Physics
- ▶ PHENIX Results on
    - ▶ Single Particles: e, μ, quarkonia
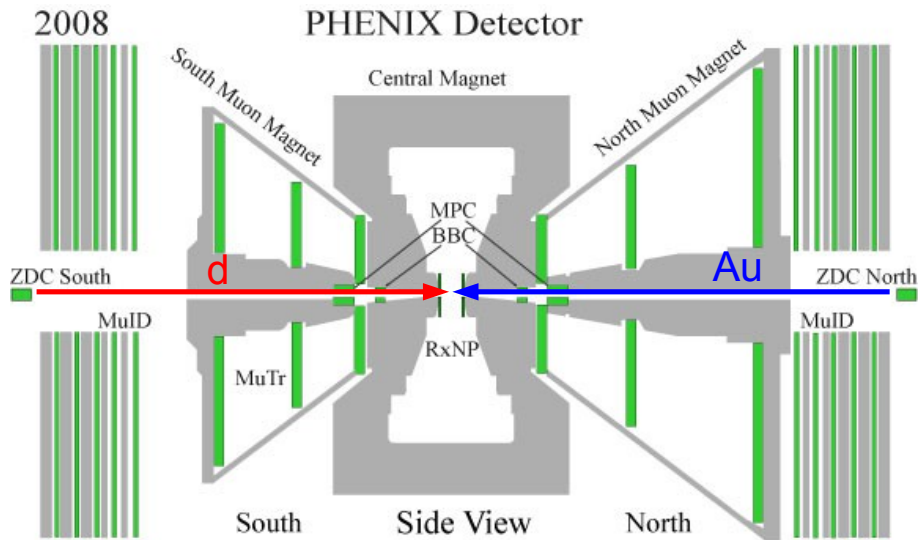   - ▶ Pairs: ee, $e\mu$
- ▶ Conclusions

Heavy Flavors in $d+$Au

Nagle, Frawley, Linden-Levy, and Wysocki

Phys. Rev. **C84** 044911 (2011)

- ▶ Charm and Bottom access
  - ▶ gluon nPDF – shadowing and/or saturation
  - ▶ interactions with the cold nuclear medium – Cronin and energy loss
- ▶ Quarkonia additionally access
  - ▶ Nuclear breakup
  - ▶ Recombination

2008 RHIC d+Au Run

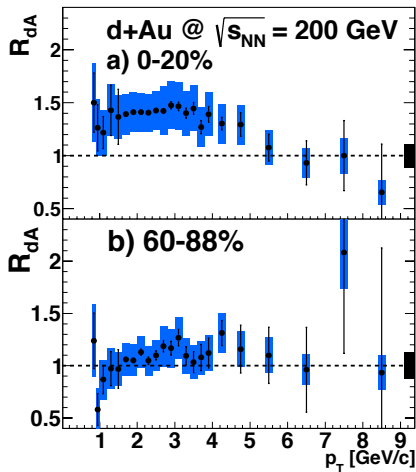# PHENIX Heavy Flavor Measurements

2008   PHENIX Detector
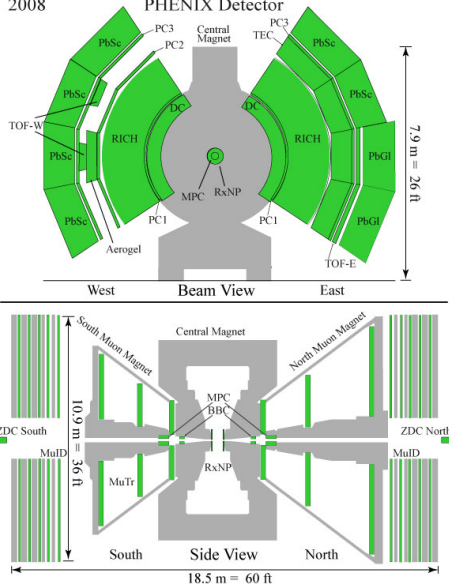
- $c, b \to \ell$ in North, South, central arms
- $J/\psi \to \ell^+\ell^-$ in North, South central arms
- $\psi' \to e^+e^-$, $\chi_c \to e^+e^-\gamma$, central arms
- $c\bar{c}, b\bar{b} \to e^+e^-$ central arms
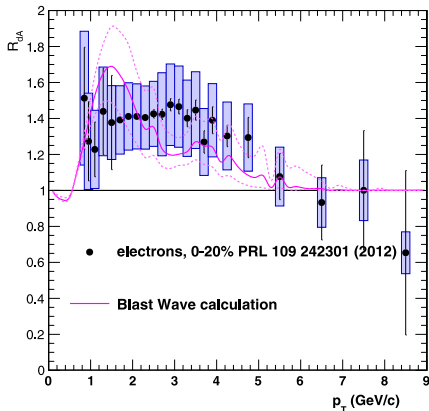- $c\bar{c} \to e^{\pm}\mu^{\mp}$ in central-muon arms

Heavy Flavor e at Midrapidity

$$R_{dA} = \frac{d + Au\ yield}{\langle N_{coll} \rangle \times p + p\ yield}$$

▶ Peripheral – consistent with binary scaling.

▶ Central – enhancement.

▶ Multiple scattering in heavy flavors more than light?

Phys. Rev. Lett. **109**, 242301 (2012)

Further Evidence of Hydrodynamics in d+Au?

electrons, 0-20% PRL 109 242301 (2012)

Blast Wave calculation

A. Sickles Phys. Lett. **B731** 51 (2014)

▶ Blast wave constrained to light flavors p_T spectrum.
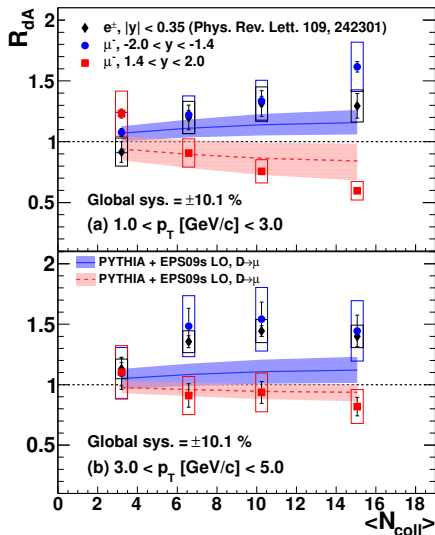
▶ Substantial enhancement to electrons.

Heavy-Flavor μ R_{dAu}

arXiv:1310.1005
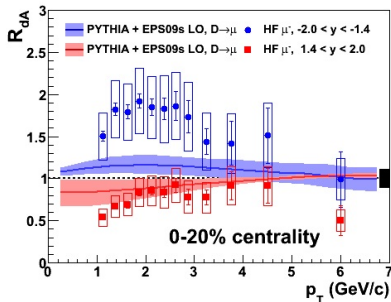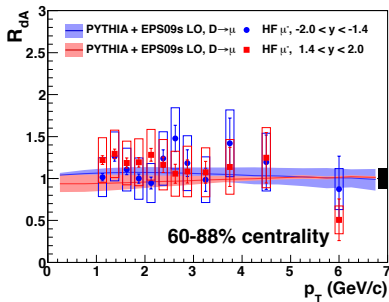
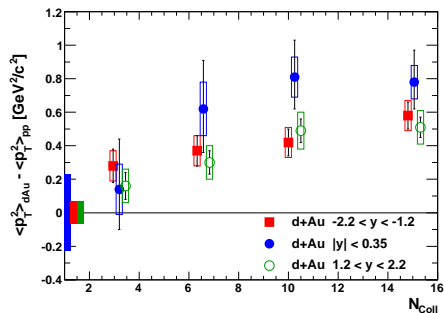- ▶ PYTHIA $D \to \mu$ weighted with EPS09 b-dependent nPDFs
- ▶ Additional effects beyond anti-shadowing are necessary to explain backward (Au-going) rapidity
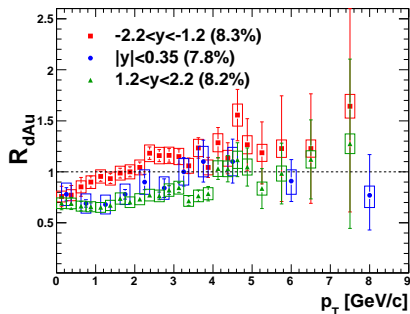
Heavy-Flavor R_{dAu} vs. Centrality

arXiv:1310.1005

- ▶ Comparison μ and e R_{dAu}
- ▶ Top $1 < p_T < 3$ GeV/c, Bottom $3 < p_T < 5$ GeV/c
- ▶ Au-going rapidity μ enhanced like e
- ▶ b-dependence of data is stronger than EPS09s.

J/ψ $\langle p_T^2 \rangle$

Phys. Rev. C 87, 034904 (2013)

- ▶ J/ψ p_T distribution broadens.
- ▶ More broadening observed at backward (Au-going) rapidities.

J/ψ R_{dAu}

2.5

2

R_{dAu} 1.5

1

0.5

0

■ -2.2<y<-1.2 (8.3%)
● |y|<0.35 (7.8%)
▲ 1.2<y<2.2 (8.2%)

0 1 2 3 4 5 6 7 8 9

p_T [GeV/c]

Phys. Rev. C 87, 034904 (2013)

▶ Centrality-integrated R_{dAu} for different y ranges.

▶ Green – d-going, Blue – midrapidity, and Red – Au-going

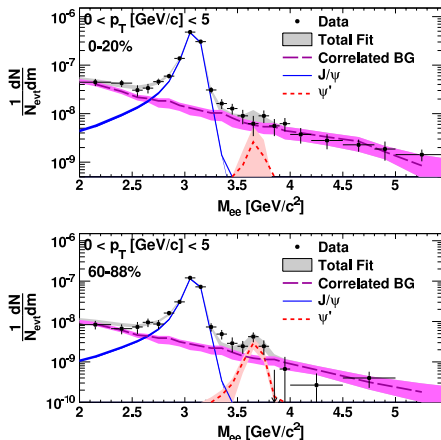# J/ψ R_{dAu}

- ▶ Full p_T, y and centrality dependence
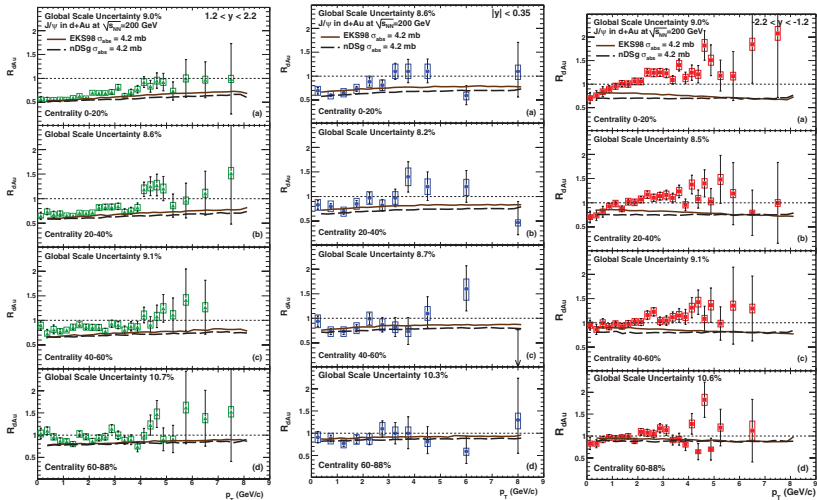
Midrapidity ψ' in d+Au

- ▶ $\psi' \to e^+e^-$ at mid rapidity in central (top) and peripheral (bottom) d+Au collisions.
- ▶ Curves
  - ▶ Quarkonia decays – QED calculation smeared by PHENIX mass resolution
  - ▶ PYTHIA Drell-Yan
  - ▶ PYTHIA and MC@NLO open heavy flavor
- ▶ Grey curve – sum with relative normalization of components a free parameter.
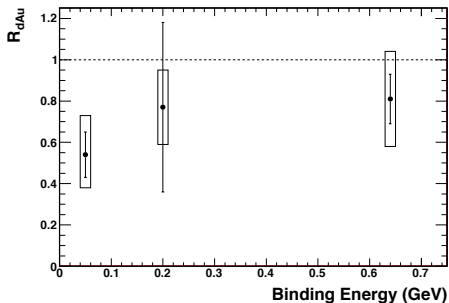
Midrapidity ψ' in d+Au

Phys. Rev. Lett. **111**, 202301 (2013)
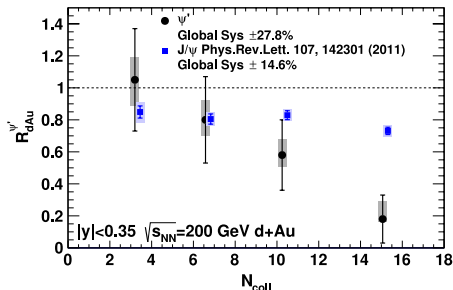
- ▶ ψ' substantially suppressed in most central collisions.
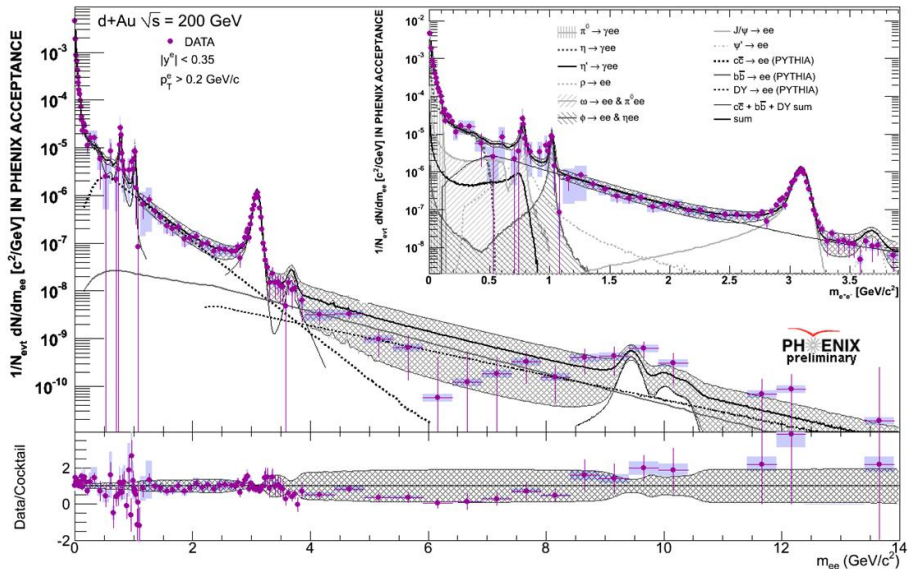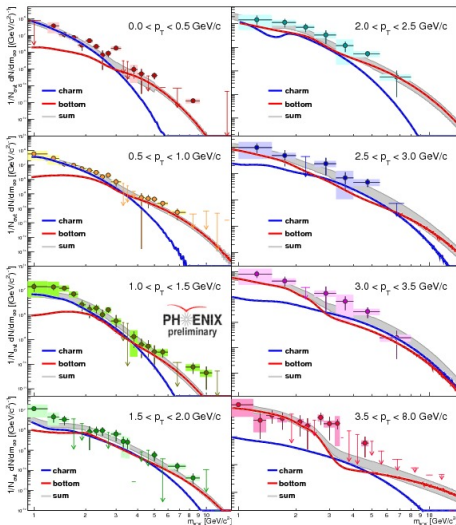- ▶ More suppressed than J/ψ in most central.

Prompt Quarkonia R_{dAu}

Phys. Rev. Lett. **111**, 202301 (2013)

- ▶ Measure $J/\psi \to \chi_c$ feed down in $p+p$ and $d+$Au
  - ▶ χ_c R_{dAu} from inclusive J/ψ R_{dAu}.
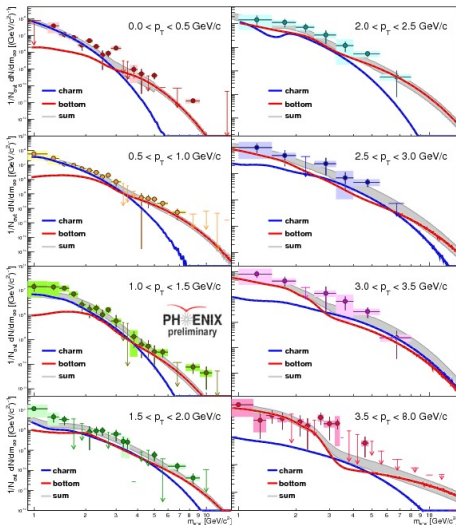- ▶ From ψ' and χ_c R_{dAu} extract prompt J/ψ R_{dAu}.

Dielectrons

Heavy-Flavor Dielectrons in p_T and and mass

- ▶ Subtract vector mesons and Drell-Yan from data as a function of mass and p_T.
- ▶ Line shape of $c\bar{c} \rightarrow ee$ (blue) and $b\bar{b} \rightarrow ee$ (red) from MC@NLO
- ▶ Fit to the data where normalization of each are free parameters.
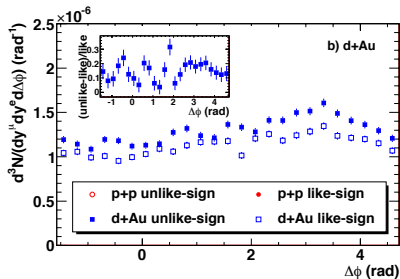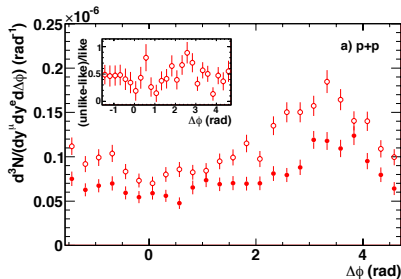
Heavy-Flavor Dielectrons in p_T and and mass

- Bottom dominates at
    - $m_{ee} > 4$ GeV/c^2 for all p_T
    - $p_T > 2.5$ GeV/c for all m_{ee}
- Extract cross sections for both charm and bottom

$$\begin{aligned}
\sigma_{cc}^{pp} &= 704 \pm 47(\mathrm{stat}) \\
&\quad \pm 40(\mathrm{model}) \; \mu b \\
\sigma_{bb}^{pp} &= 4.29 \pm 0.39(\mathrm{stat}) \\
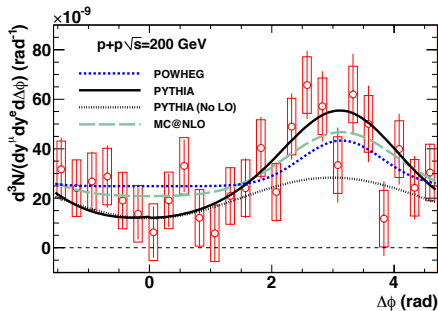&\quad \pm 0.11(\mathrm{model}) \mu b
\end{aligned}$$

Heavy-Flavor $e - \mu$ Correlations

- $e^{\pm}$: $p_T > 0.5$ GeV, $|\eta| < 0.35$
- $\mu^{\pm}$: $p_T > 1.0$ GeV, $1.4 < \eta < 2.1$, in deuteron direction
- Like-sign subtraction removes almost all light-hadron backgrounds.
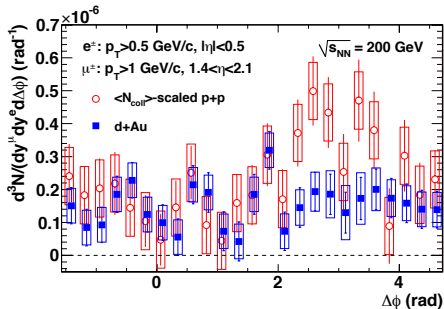
Heavy-Flavor $e - \mu$ Correlations

Phys. Rev. **C89**, 034915 (2014)

- Comparison of $p + p$ PYTHIA, POWHEG, and MC@NLO
- Peak dominated by gluon fusion, pedestal from flavor excitation and gluon splitting.
- Extracted a cross section by normalizing shape to $p + p$ data uncertainties.

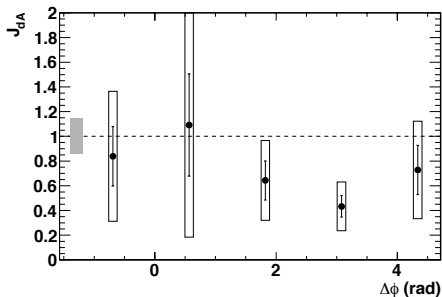$$\sigma_{c\bar{c}} = 538 \pm 46(\text{stat}) \pm 197(\text{data syst}) \pm 174(\text{model syst}) \ \mu\text{b}$$

Heavy-Flavor $e - \mu$ Correlations

Phys. Rev. **C89**, 034915 (2014)

- ▶ $\langle N_{coll} \rangle$-scaled $p + p$ compared to $d+$Au.
- ▶ Lack of defined peak in $d+$Au correlations.
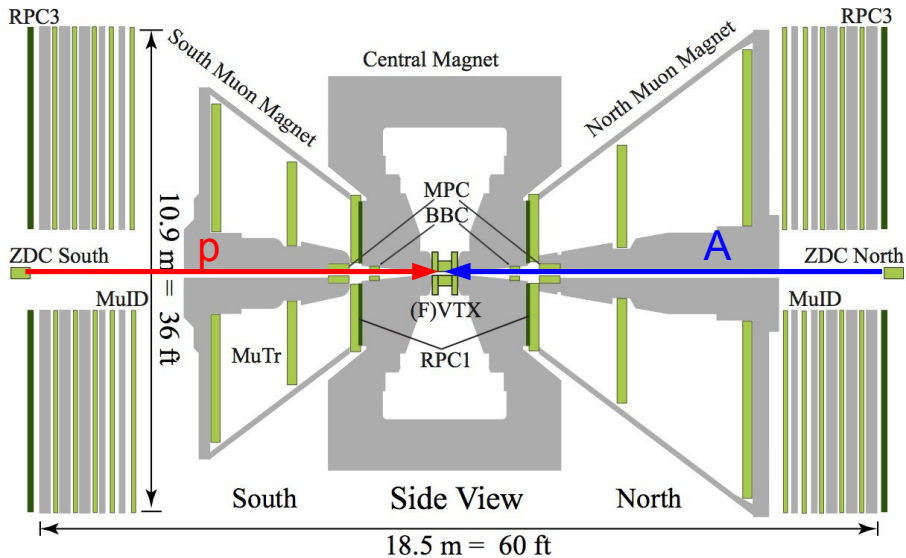
Heavy-Flavor $e - \mu$ Correlations

- J_{dA} pair modification factor.

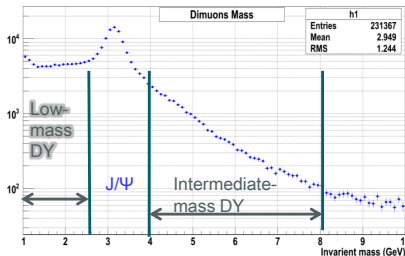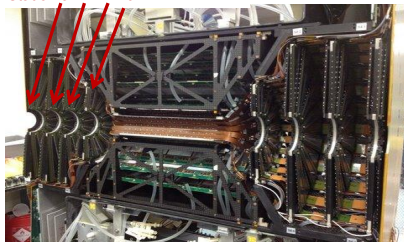$$J_{dA} = \frac{\mathrm{d + Au\ yield}}{\langle N_{coll} \rangle \times \mathrm{p + p\ yield}}$$

- $x \sim 10^{-2}$ at $Q^2 = 10$ GeV^2, at the edge of the shadowing region.
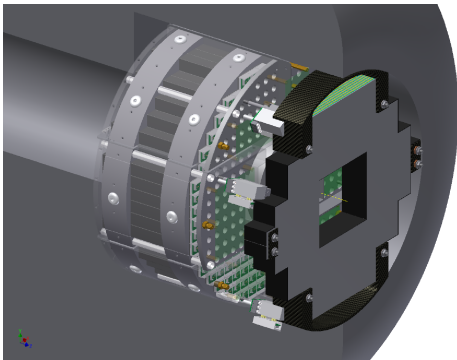
RHIC 2015 p+A Run

# Heavy Flavor Production: (F)VTX

- ► (F)VTX installed
- ► Right: $\mu^+\mu^-$ mass distribution in 510 GeV $p + p$
- ► Ahead: Forward μ, J/ψ production in $p+$A, direct displaced D decay vertices at midrapidity
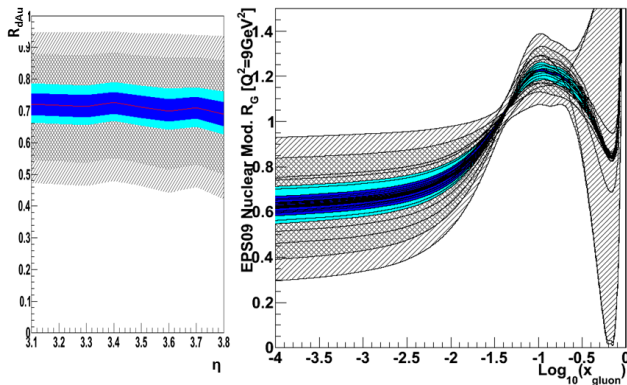
Constraining the Gluon nPDF: MPC-EX

- ▶ Silicon pre-shower in front of MPC ($3.0 < |\eta| < 3.8$) installation Summer 2014.

- ▶ Finely segmented silicon to vector photons from the vertex.

- ▶ Take advantage of the "golden channel" of QCD Compton scattering in $p+A$.
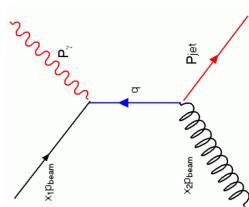
Constraining the Gluon nPDF: MPC-EX

- ▶ Separate γ from π^0 up to 80 GeV in energy.
- ▶ Color: expected measure 1σ inner, 90% confidence outer
- ▶ Hatched: EPS09 1σ inner and 90% confidence outer

Conclusions

▶ PHENIX has measured many heavy flavor and quarkonia observables that span different p_T, y, and x ranges.

▶ Enough to disentangle competing effects of gluon nPDF modifications, energy loss, and hydro?

▶ Future plans to extend the quality and quantity of the measurements.